

DAMAGE DETECTION IN COMPOSITE PLATE ARMOR USING ULTRASONIC TECHNIQUES (U)

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(U) ABSTRACT

(U) A method for crack and damage detection in ceramic composite plate armors is presented. The method uses embedded piezoelectric Lead Zirconate Titanate (PZT) transducers to characterize the vibrational modes of composite armor plates. The amplitudes of the vibrational modes of damaged and undamaged plates are shown to be distinct. The differences in the vibration modes can be exploited to detect cracks and damage. Composite armor plates for testing are damaged by impact with a certain caliber round. Data from these tests can be used to design a vehicle based system for the nondestructive testing (NDT) and health monitoring of the armor plate structural integrity.

(U) Introduction

(U) This paper describes a new type of armor called Sensor Enhanced Armor (SEA). The traditional method for evaluating armor health is visual inspection. This can be dangerous during combat situations. In addition armor can be damaged internally (for example the armor plate can be damaged in a minor collision) and a visual inspection may not reveal any damage. Our method relies on attaching embedded transducers to an armor plate. The armor plate is then subjected to ultrasonic vibrations of varying frequencies.

(U) The response curve for an undamaged plate is quite different from that of a damaged plate. By storing the results for the undamaged plate we have a baseline which represents a healthy plate. At any time in the future we can retest the plate. If the results of the retest differ greatly from that of the healthy plate we can conclude that the plate has been damaged. We are working on an algorithm and metric to be able to precisely measure the differences between a healthy and a damaged armor plate without a need for human inspection.

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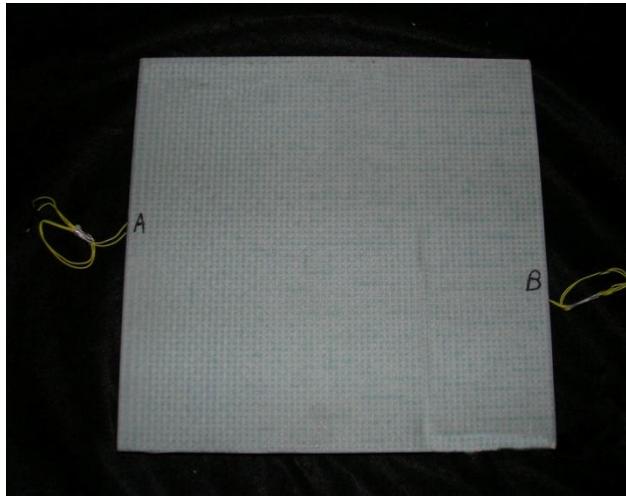


Figure 1. (U) Armor Plate with Embedded Sensors

(U) General Description of the Method

- (U) Ultrasonic sensors are bonded to the armor plate. A signal generator is then used to pass electronic signals of varying frequencies through these sensors. The reaction of the plate can then be recorded on a computer. A computer program was written to control the excitation of these sensors and analyze the signals that are returned from passing through the plate. Data is then collected by the following method: An ultrasonic signal is sent through the plate at frequencies varying from 1 kHz to 200 kHz. A signal is sent from sensor A in Figure 1 and is received at sensor B. The strength of the signal received at B depends upon the voltage of the input signal and the physical properties of the plate. The input

signal is always of the same strength, but there will be differences in the amplitude of the output signal because the plate is more sensitive to some frequencies than others. By this method 200 data points are collected from each test, one for each frequency. The placement of the sensors is important because it has an effect on the plate's vibration. The sensors can be placed on either the top surface of the armor plate or in the sides of the plate as in Figure 1.

- (U) The test is then repeated several times under varying environmental conditions such as temperature and humidity to collect data which are the basis for the plate's signature when it is in a "healthy" or undamaged state. The plate should be tested at least 10 times to provide a good baseline. Each test gives a vector of 200 points, and we can average the data from several tests to get the general shape of the curve of a healthy plate. The equation which can be used to define the representative curve is as follows:

$$x(i) = \frac{1}{n} \sum_{j=1}^n y_j(i)$$

where $x(i)$ is the i^{th} coordinate of the representative curve and $y_j(i)$ is the i^{th} coordinate of $y_j(i)$ where j represents the j^{th} test, and i varies between 1 and 200.

- (U) Similarly the standard deviation at each point i is defined

by

$$\sigma(i) = \sqrt{E[y(i)^2] - E[y(i)]^2}$$

where E denotes expected value.

changed. We can then compare the data from the retest to the known good data to determine if the plate is still healthy.

- (U) At some later time we can retest the plate to see if it has

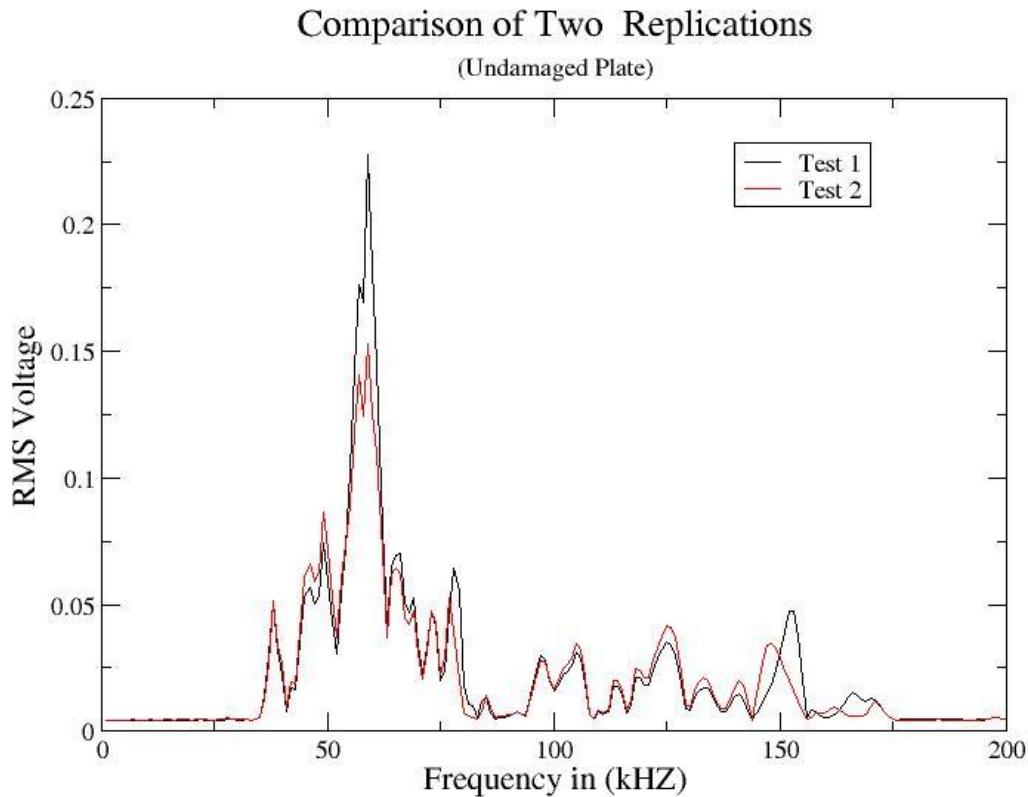


Figure 2. (U) Comparing Two Replications of Testing an Undamaged Plate

- (U) Figure 2 shows the two replications on the same graph.

(U) The photograph in Figure 3 shows the results of impacting an armor plate with a ballistic round.

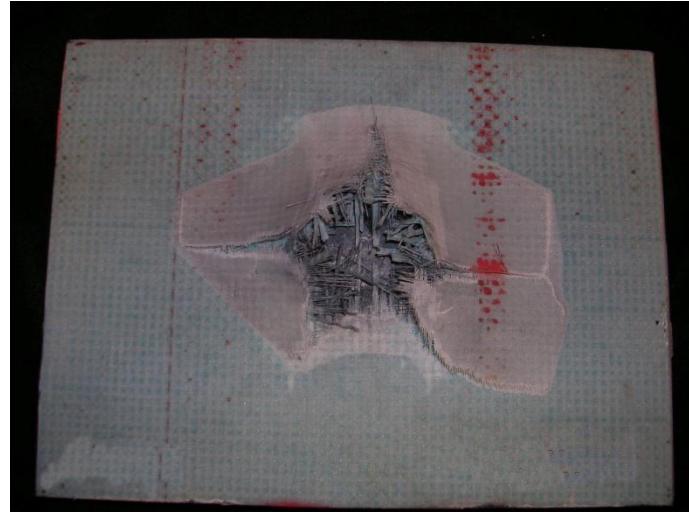


Figure 3. (U) Plate after Impact

(U) Figure 4 shows the results of two replications of the damaged plate.

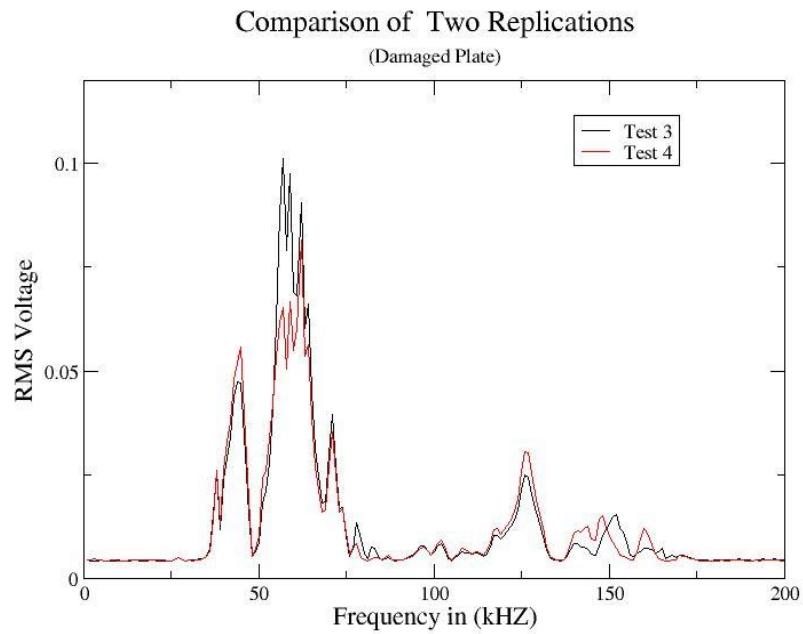


Figure 4. (U) Comparing Two Replications of Testing a Damaged Plate

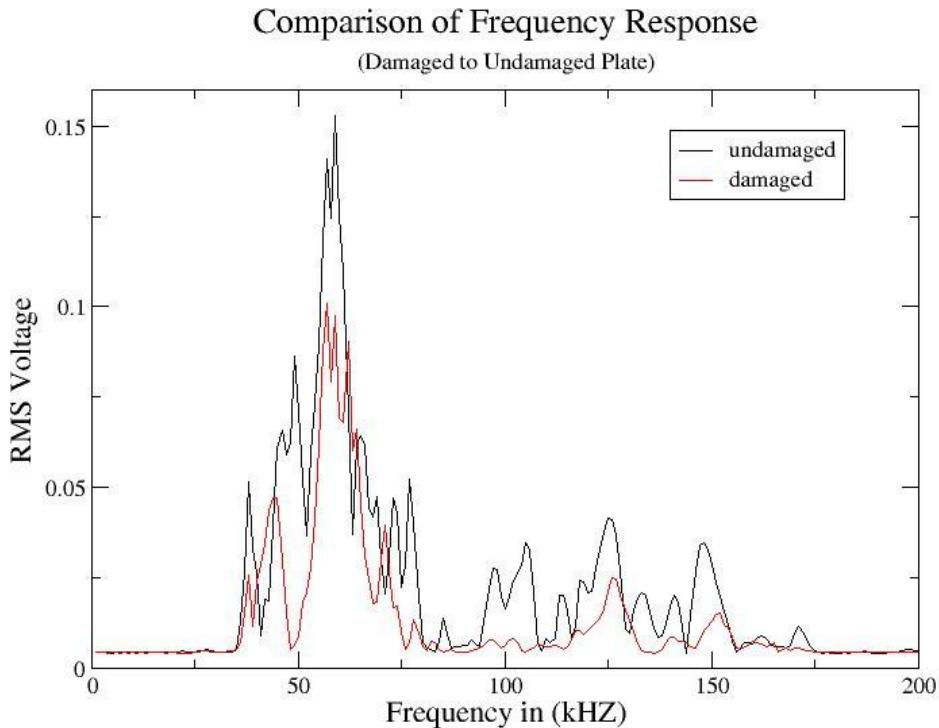


Figure 5. (U) Comparing the Frequency Response of a Damaged Plate to an Undamaged Plate

(U) Figure 5 shows that the response of a damaged plate differs quite a bit from that of an undamaged plate in several frequencies. In particular we can observe that for frequencies over 100 kHz the undamaged plate displays many more peaks than the damaged one. We are working on a metric that will more precisely measure the differences in frequency response between a damaged and undamaged plate. This will permit the determination of armor health without human intervention.

(U) Conclusions

(U) The authors have demonstrated how ultrasonic signals generated by piezoelectric transducers can be used to provide real-time health monitoring for a class of armor known as ceramic composite armor. Future work will entail extending this technique to other armor designs and optimizing the sensor system design.

(U) References

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